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It starts at home? Climate policies targeting household consumption and behavioral decisions are key to low-carbon futures

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A B S T R A C T

Through their consumption behavior, households are responsible for 72% of global greenhouse gas emissions. Thus, they are key actors in reaching the 1.5 °C goal under the Paris Agreement. However, the possible contribution and position of households in climate policies is neither well understood, nor do households receive sufficiently high priority in current climate policy strategies. This paper investigates how behavioral change can achieve a substantial reduction in greenhouse gas emissions in European high-income countries. It uses theoretical thinking and some core results from the HOPE research project, which investigated household preferences for reducing emissions in four European cities in France, Germany, Norway and Sweden. The paper makes five major points: First, car and plane mobility, meat and dairy consumption, as well as heating are the most dominant components of household footprints. Second, household living situations (demographics, size of home) greatly influence the household potential to reduce their footprint, even more than country or city location. Third, household decisions can be sequential and temporally dynamic, shifting through different phases such as childhood, adulthood, and illness. Fourth, short term voluntary efforts will not be sufficient by themselves to reach the drastic reductions needed to achieve the 1.5 °C goal; instead, households need a regulatory framework supporting their behavioral changes. Fifth, there is a mismatch between the roles and responsibilities conveyed by current climate policies and household perceptions of responsibility. We then conclude with further recommendations for research and policy.

Abbreviations: CF, carbon footprint; CO_2e, carbon dioxide equivalent; CU, consumption unit; EE, energy efficiency; EU, European Union; FCS, Footprint Calculation and Simulation; HH, household; HOPE, HOusehold Preferences for reducing greenhouse gas emissions in four European high-income countries; IPCC, Intergovernmental Panel on Climate Change; OECD, Organization of Economic Co-operation and Development

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1. Background and theory

Household consumption contributes to 72% of global greenhouse gas emissions (with the remainder coming from public and non-governmental and financial sources) [1]. Household behavior therefore is an essential component in climate policies, especially in high income countries such as those in Europe, Australia and North America [2]. We need to know how willing households are to change, and to what extent proactive behavioral changes will be mobilized by climate policy-making [3]. According to Cafaro, individuals can save immense amounts of carbon in a so-called "behavioral mitigation wedge"—as much as 15 billion tons (gigatons) by 2060—simply by changing their diet to avoid meat, or by forgoing air travel [4]. A slew of other recent studies emphasize the climate change or sustainability co-benefits of less carbon intensive diets and food practices [5–7]. Other data from the Tyndall center underscores the sheer magnitude of emissions reductions that behavioral change can accomplish—far more than low carbon infrastructural supply or the political pledges under the Paris Accord [8].

The international climate policy debate has been fixated on technology and economic incentives and has often relegated behavioral change to an afterthought, rather than having it join the center stage. The implication is we must become much more focused on changing consumption, or demand side options, in addition to emphasizing mitigation via technology or policy on the supply side [9,10]. We must also consider lifestyles as targets of policies (and modeling efforts) [11], rather than a voluntary add-on by individuals.

Indeed, very steep reductions in emissions are needed if the global community is to meet the goals of the Paris Agreement, which translate into a reduction of emissions from 40 gigatons of carbon dioxide in 2020 to 5 gigatons in 2050, and eventually reach a level of "net zero" by 2100. Essentially, this necessitates that emissions must halve every decade *in perpetuity* until the middle of the century, and then cross the line and continue with implementing so-called negative emissions measures until the end of the century [12]. We must accelerate transitions toward "deep decarbonisation" [13] and a "post carbon society" [14] by 2050, if not sooner.

Due to such stringent targets, climate change mitigation will increasingly affect households and their lifestyles. Yet neither existing mitigation policies nor the Nationally Determined Contributions under the Paris Accord keep emissions on track with an emission pathway compatible with the 1.5 °C goal [15–17]. We need additional contributions, potentially available in even more efficient production systems and negative emission technologies, but also in household lifestyles and individual behavioral change [18,19].

We then require a more balanced approach between consumption and production regarding emission inventories and mitigation strategies [20], and a more nuanced understanding of what can motivate the household adoption of low-carbon lifestyles and technologies, be these changes reactive (i.e. the indirect results of other policy measures) or proactive (households being the main drivers for change) [21]. There is a strong need to understand the barriers and motivations for consumption changes at the individual level of consumers [22], especially when connected to the urgency of global decarbonisation pathways.

Drawn from a mix of methods as part of a four year project called HOPE—household carbon footprint assessments, simulations, and qualitative research interviews as well as policy reviews and analysis—this paper shows how behavioral change can reduce household carbon footprints substantially by 2050. Academic debates have begun to stress the need to supplement current climate policies with that of addressing behavioral changes to a higher degree as compared to that of addressing technical changes in production and infrastructure changes. As the IPCC noted with "high confidence" recently in their 1.5 °C report, "pathways that include low energy demand (…), low material consumption, and low GHG-intensive food consumption have the most pronounced synergies and the lowest number of trade-offs with respect to sustainable development" [23]. The mission of the HOPE project was to investigate the potential policy-room for maneuver on this particular point. Furthermore, we wanted, by means of involving household representatives in the HOPE climate game, to trigger deep reflections on public acceptance as to how such policy interventions best should be carried out with respect to choosing between "carrots, sticks and sermons" [24].

2. Research design: an interdisciplinary mixed-methods approach

To make the case for the salience of behavioral change, we draw from original primary data resulting from a four-year, comparative, mixed-methods project called HOPE (HOusehold Preferences for reducing greenhouse gas Emissions in four European high-income countries) [25–28]. More details are presented in Appendix A.

The HOPE project was an interdisciplinary study, which investigated the preferences of households across four cities in France, Germany, Norway and Sweden. These four countries are admittedly not representative of the world in the statistical sense. However, results are generalizable to urban settings in OECD countries, a point which is corroborated by the fact that relative and absolute carbon footprints between the four cities and household preferences are very similar. Each household was involved into the research for four to six hours. Thus, one strength of the project is to provide deep insights into 308 household cases by triangulating results from questionnaires, simulations and qualitative interviews and comparing the results from the household analysis with an analysis of current policies.

In the HOPE project, we selected the goal of halving household greenhouse gas emissions by 2030 to represent the effort needed by households to do their part toward achieving the 1.5-degree goal [29]. Our results derive from four distinct methods: (1) the estimation and mapping of household carbon footprints, (2) the output of a climate change mitigation simulation game with households, (3) in-depth qualitative interviews, and (4) the depiction of climate policy measures that are explicitly or implicitly aimed at influencing household consumption in order to reduce greenhouse gas emissions.

All greenhouse gases were considered and accounted for as a carbon dioxide equivalent (CO_2e). The HOPE project conducted methods (1) and (2) across 308 households in four mid-sized European cities – Pays d'Aix-en-Provence, France; Mannheim, Germany; Bergen, Norway; and Umeå, Sweden. Method (3) was conducted for a subset of 64 households. Method (4) included the mapping of relevant policy measures issued at the local (the four case cities), regional (host-counties of the four cities) and national level (the four involved countries). Quantitative and qualitative survey data as well as policy analysis were triangulated in order to maximize validity of results. For more details (beyond those offered in this section), readers are invited to see the study protocol in Appendix A.

2.1. Method 1: Mapping empirical household carbon footprints

Assessing the carbon footprint of consumption can be done either by a top-down approach, processing surveys of consumer expenditure or via national accounting systems and environmentally extended input–output analysis [30], or by a bottom-up approach, multiplying for a given household some physical or monetary unit of consumption by emission factors. Given that our aim was to support a reduction simulation process at the individual level, the latter was chosen.

In order to survey households preferences in reducing their carbon footprint we therefore developed a tool allowing a) the accurate mapping of empirical real household footprints, and b) a dynamic simulation process, informing households about the anticipated greenhouse gas equivalent savings, financial costs and savings, and for half of the sample the health consequences of their sequential choices. This Footprint Calculation and Simulation Tool (FCS-Tool) [31] was built based on a first Microsoft Excel prototype [32] and further adapted to national contexts, e.g. particular emission factors of the four countries. The FCS was based on an in-depth tailoring of solutions (e.g. basing the calculation of CO_2e savings from wall insulation on the actual size of the house, the type of insulation, and household heating supply), on a dynamic computation of avoided greenhouse gas emissions (to avoid double counts, already implemented solutions, etc.) and on the valuation of financial costs and savings (for more details on dynamic computation see Appendix A and other published studies from the HOPE project) [33–37].

The resulting carbon footprints convert household inputs on their consumption behavior, expressed in financial or physical units, into CO_2e emissions. This is done by using greenhouse gas emissions factors, adapted from international or national sources. The initial survey covered 400 data entries for household consumption, their expenditure on consumption and socioeconomic data. This household consumption included all fields of personal consumption in housing, mobility, food and other consumption (such as clothing, furniture, electronics, etc.). We did not explicitly consider public services like education and health. However, we did consider CO_2 emissions of expenditures for insurance, in order to capture some of these goods and services. Approximately 100 consumption data entries were converted to CO_2e. The data allows for a deeper and more detailed description of household emission patterns as well as the simulation of different household emission pathways and their net cost implications for the households.

2.2. Method 2: Interactive mitigation simulation game with households

In attempting to capture how behavioral mitigation wedges could work in practice, we asked households to consider the intensity and extent of an array of tailored mitigation actions. In three rounds described more in Appendix A, households rated and selected these actions. This "serious gaming" method [38,39] comprised 65 emission reduction options, grouped into "Action Cards" in the areas of food, housing, mobility and other consumption. For each action, we provided information on its CO_2e savings, its positive or negative financial costs, and its health impact when relevant. In order to encourage participation and minimize the risk of selection bias (i.e., that only environmentally concerned people would participate), we offered monetary incentives to participate in the simulation.

First, we asked household representatives to rate mitigation actions on a Likert scale from 1 (very willing) to 5 (not willing), i.e. "Imagine you would be required to reduce your carbon footprint by 50% by 2030. To reach this goal, how willing are you to implement the following actions?" Second, we asked them to consider voluntary actions, i.e. "Which actions would you actually like to implement to reduce your carbon footprint by 50% by 2030?" We finally asked them to consider "forced" or mandatory options, i.e. "Which actions would you choose if you were forced to reduce your carbon footprint by 50% by 2030? Continue your rank order from round 2. You may choose up to 30 actions in total." This choice of having a voluntary and a forced scenario allows us to distinguish the spontaneous choices from the ones made under stringent circumstances.

2.3. Method 3: Qualitative household interviews

Qualitative semi-structured in-depth interviews were carried out with a sub-sample of households participating in the simulation game using a common interview guide aiming to explore their knowledge and perception of climate change and household mitigation options. Maximum variation sampling was used to recruit a diverse set of informants covering a diversity of socioeconomic characteristics such as age, gender, income, education, type of housing, location of housing, etc. [40]. In addition, recruitment of interviewees was informed by findings from methods 1 and 2, such as households with big or small initial footprints and high or low rates of reduction. The final sample size of each country sample was determined by the qualitative principle of data saturation [41]. Following this method, we reached a final sample size of 64 interviews across all countries for the qualitative study component.

2.4. Method 4: Policy analysis

Assessing the efficacy of climate policies, and thus also comparing the outcome between different nations, regions or public bodies, has gained increased research attention as the recognition that more ambitious mitigation efforts needs to be in place has also increased. Still, there is a limited knowledge with respect to comparability of findings in this area of research, often owing to lack of a common understanding of what policy output "is", and highly variable methods for comparing policy outputs [42] and defining the object of comparison [43]. The "proof of the pudding" when comparing and measuring the success of climate policy would be to assess the actual reduction of greenhouse gas emissions, but that would entail a very comprehensive research design far outside of the resource limit of the HOPE project.

Thus, we had to settle with collecting indicators of policy success. A frequently used approach, also in climate policy studies, is to analyze the policy density, i.e. the number of policy instruments [44,45]. This rather simplistic approach has its disadvantages, most obvious that of counting "apples and pears" and giving equal weight to powerful as compared to less powerful policy measures. This can be partly counteracted by choosing a policy taxonomy that allows for some sort of differentiation as to mitigation potential. Furthermore, even a simplistic way of counting policy measures can allow for doing valid relative – if not absolute – comparison between the chosen objects of study.

For each of the four countries, we mapped their energy and climate "policies" to that of the more tangible output of political processes [46]. Moreover, we limited the scope of coverage to that of plans, strategies and steering instruments designed to achieve policy goals that are approved through political processes [47]. This meant our policy analysis began by examining exactly what "policies" were available and suggested in official documents like government green papers, white papers, and legislative acts [25].

The aim of the policy mapping was to categorize any policies that affect household greenhouse gas emissions either directly or indirectly. Our mapping generally excluded supply-side policies (i.e. policies aimed at reducing greenhouse gas emissions from production) unless they fell into a gray zone (i.e. city planning for mobility or fuel mix regulations). The focus was on policies issued by government bodies at the national level, as well as the regional and local levels of the case city. EU policies were assumed to be implemented at subsidiary levels of government and therefore not mapped separately.

Policy data was gathered through the Odyssee-Mure database [49], official reports to international organizations and government databases from the national, regional and local levels of government. The resulting corpus included 250 policies that were coded along three dimensions in accordance with the policy categories used in the IPCC Fifth Assessment Report [50]: (1) policy area (housing, mobility, food and other consumption); (2) anticipated policy mechanism (change patterns or volumes of consumption); and (3) policy instruments (economic instruments, information policies, public goods and services, and regulatory approaches).

2.5. Setting technical and behavioral targets

With our methods established, our next task was to propose a quantified target for a behavioral-related reduction of household greenhouse gas emissions, in the context of low carbon scenarios, to a time horizon that remained imaginable for the interviewees.

Technical energy efficiency solutions essentially reduce emissions per unit of production (e.g. from manufacturing private cars) and/or offering products or services with lower emissions per unit of consumption (e.g. private cars with better mileage). For this to result in absolute reductions of emissions—and not merely relative reductions—we also need to obtain control over or abate rebound effects [51,52], which are always challenging to model accurately [53]. The extent of non-mitigated rebound effects is thus an important reason why technical improvements do not always meet projected reductions in greenhouse gas emissions [54,55].

Behavioral solutions involve an active effort in changing the nature, or in some cases the amount, of consumption. This can be presented in order of qualitative changes to take place, i.e. across a typology of (1) renouncement, e.g. giving up owning a car; (2) reduction, e.g. reducing your mobility; (3) substitution between categories of consumption, e.g. using public transportation instead of a private car; and (4) substitution within a specific category of consumption, e.g. continue using your private car, but buying a more efficient one [56]. The two first categories deal with degrees of changing the volume of consumption, whereas the last two address qualitatively different ways of changing patterns of consumption. Later in the article, we investigate what households themselves thought about the behavioral solutions that they control across these dimensions.

Conceptually, we are interested in the notion of rapid reductions in emissions or greatly accelerating decarbonisation efforts. Although a combined pace of technical efficiency and behavioral solutions of 1% per annum would lead to a halving of emissions in 2050, a combined pace of 3% would (theoretically) reduce emissions almost by a factor 10 greater in 2050. Consequently, our project was implicitly embedded in the vision of a transition toward a very low carbon society. Indeed this reference objective of minus 50% reduction by 2030 due to behavioral change, combined with technical energy efficiency (with a control of the potential rebound effect), would correspond to an overall mitigation of more than 70% of household emissions by 2030 and 95% by 2050. In annual terms, this corresponds to a faster pace of 4% in reductions per year, largely compatible with a 1.5 °C warming scenario by 2100.

3. The complexity of household decision-making: five empirical insights

This section makes five major points, which we derive from some core empirical and conceptual findings from the HOPE project. These are: (1) that car and plane mobility, meat and dairy consumption, and heating dominate footprints; (2) that household living situations or demographics influence preferences and possibilities for greenhouse gas reduction while there is little difference between countries; (3) that household decisions can be sequential and temporally dynamic; (4) that voluntary efforts will not be sufficient by themselves to achieve drastic reductions; and (5) that there is a mismatch between the roles and responsibilities conveyed by current climate policies and household perceptions of responsibility. Again, more data about the specific methodologies or details behind these findings is offered in Appendix A.

3.1. Mobility, food, and heating dominate household consumption footprints

The baseline carbon footprint (CF) assessments of households participating in the HOPE study found the mobility sector to be the most significant contributor to a median household's footprint. Emissions of greenhouse gases were accounted for by CO_2 equivalents (CO_2e). As Fig. 1 reveals, mobility made up 34% of the CF with a median value of 2.9 tons CO_2e per household member, followed by food, which made up 30%.

The CF for housing is dominated by heating, representing a total of 0.5 tons per consumption unit across all four countries, covering 44% of emissions in this sector. Emissions derive largely from energy consumption which resulted in some variations between countries depending on what major source of energy they used (nuclear, hydropower, district heating, etc.). Food footprints were dominated by red meat, dairy, and other food, and did not show country wise variation with the exception of France due to higher numbers of reported meals eaten at restaurants and schools. Mobility's baseline CF was predominantly composed of air travel, car travel, and other motorized travel.

Looking at the results geographically, the households median baseline CF was lowest for Swedish participants (7.3 tons), followed by the French (10 tons), German (10.2 tons), and Norwegian participants with 11.3 tons CO_2e per CU per year. At baseline, households in France and Germany used their car for longer daily distances (36 km and 27 km) and more often for commuting than households in Norway and Sweden (16 km and 14 km). Norwegian households in our sample used more inland flights than the rest of our sample

This sequence of relative shares of mobility, food, and housing footprints is confirmed by the literature, be it results obtained by a top down approach starting from national accounts or consumers survey (for instance Lenglart et al. [57]) or by carbon calculators. The comparison of calculators however reveals some discrepancies depending on perimeters, emission factors, and uncertainty ranges. For instance, one study calculated the emissions on a household basis (three persons) for five calculators in an Irish context [58]. After the correction of the most obvious causes of discrepancy, e.g. an uplift factor of three for aviation in one calculator, the range is reduced. A second study did the same type of exercise for another set of calculators in the United States context [59]. The discrepancy of results vary from the mean, with −60%/+46% for electricity emissions, −17%/+11% for fuel consumption, −11%/+12% for personal vehicles, −44%/+113% for air transport.

3.2. Demographics greatly influence household intention to reduce footprints, more than location

Household footprints and preferences for reducing them were very similar across countries—perhaps unsurprising given our four cities were fairly homogenous in terms of northern climate and common access to European markets—but differed along some demographic household characteristics. Utilizing Multiple Components Analysis (or MCA, see Appendix A for more details) and statistical tests (such as chi-square), differences between countries are less important than differences linked to household profiles (e.g. heating type, travel by plane or not). In simpler terms: the home country or city of the household never had a significant effect on preferences, as Fig. 2 indicates; instead, differences between subjects were not country-specific but subject-specific.

Household footprints vary first of all depending on level of income, perhaps obviously. Thus, minor variations between countries is a reflection of this (see the small variations on geographical footprints noted in Section 3.1). The main difference observed is that Norway (and partly

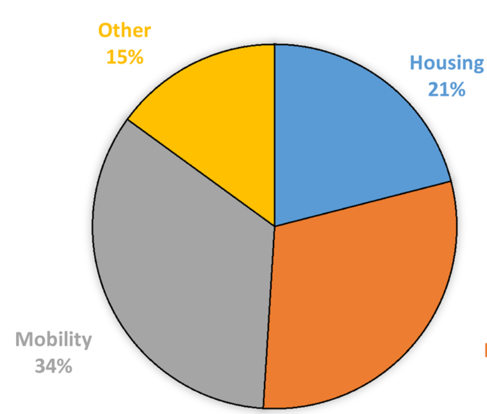

Fig. 1. Initial median carbon footprint (kg CO_2e per consumption unit per year) for HOPE households.
Source: Authors, based on HOPE data.

Sweden) has more aviation. The more obvious differences in energy supply systems, such as more hydroelectricity in Norway, and more coal in Germany, has been partially hidden since we have applied a generic Nordic electricity mix for Norway and Sweden, and a generic European mix on greenhouse gas emissions for electricity use in France and Germany.

Nonetheless, one important characteristic influencing preferences was home ownership. Many actions in the housing sector with high potential for emissions reduction were not feasible for renters, especially rental units occupied by younger households living close to city centers. According to the qualitative interviews, renters often thought that it was hard to find an apartment meeting the highest energy efficiency standards and that renovation of their current apartment was up to their landlord. The landlords (or owners) themselves argued for subsidies for their investments in energy efficiency and asked for simpler procedures.

This suggest that despite differences in climate, policy, and other national contexts, differences in reducing footprints were not country specific but largely household specific. Thus, there is tremendous potential for developing more policies to reduce consumption-related greenhouse gas emissions on the European level. However, according to Ivanova et al. [30], the carbon footprint per capita of Europeans (based on consumer surveys and environmentally extended input-output analysis) show more important differences, ranging from 5 tons of CO_2e per capita in Romania to more than 16 tons of CO_2e per capita in Finland, northern Greece, or the United Kingdom.

3.3. Household decisions and preferences can be sequential or ephemeral

Conceptually, household carbon footprints are not static: there are key strategic moments such as when a person decides where to live, where to invest, whether to buy a car or not, or whether to build a house or not, which can be significant. Similarly, major life events such as graduating from university, having children, buying a house, having the children leave home, retiring, or suffering a medical condition can also substantially affect emissions trajectories. Büchs et al. for instance reported that incidences of illness and poor health are generally linked to lower home energy use and reduced mobility, but that it is also linked to higher electricity consumption when income and other demographic attributes are controlled for [60]. Sovacool et al. found that old age was associated with greater mobility needs as well as a stronger preference for conventional cars [61].

Fig. 3 illustrates the temporality or ephemerality of theoretical carbon footprints in the HOPE project, showing how household consumption patterns can change significantly based on strategic decisions and major life events. The top panel (3A) presents one potential trajectory, showing the sequential nature of emissions related to household decisions about mobility. The bottom panel (3B) shows evolution of housing and mobility related emissions across a typified life, based on cross-sectional data from HOPE carbon footprints. The punctuated equilibrium of emissions that results is heavily influenced by major life events such as having children, retiring, or falling ill.

3.4. The greater the mitigation potential of an action, the less willing are households to implement them

Voluntary actions are limited and insufficient in the reductions they can secure. During the HOPE simulation game, households were asked to choose up to 65 different mitigation actions across the dimensions of food and recycling, housing, mobility, and other consumption. In the consumption category for food and recycling, households reached more of their total reduction (56%) in the voluntary round (36%) than in the

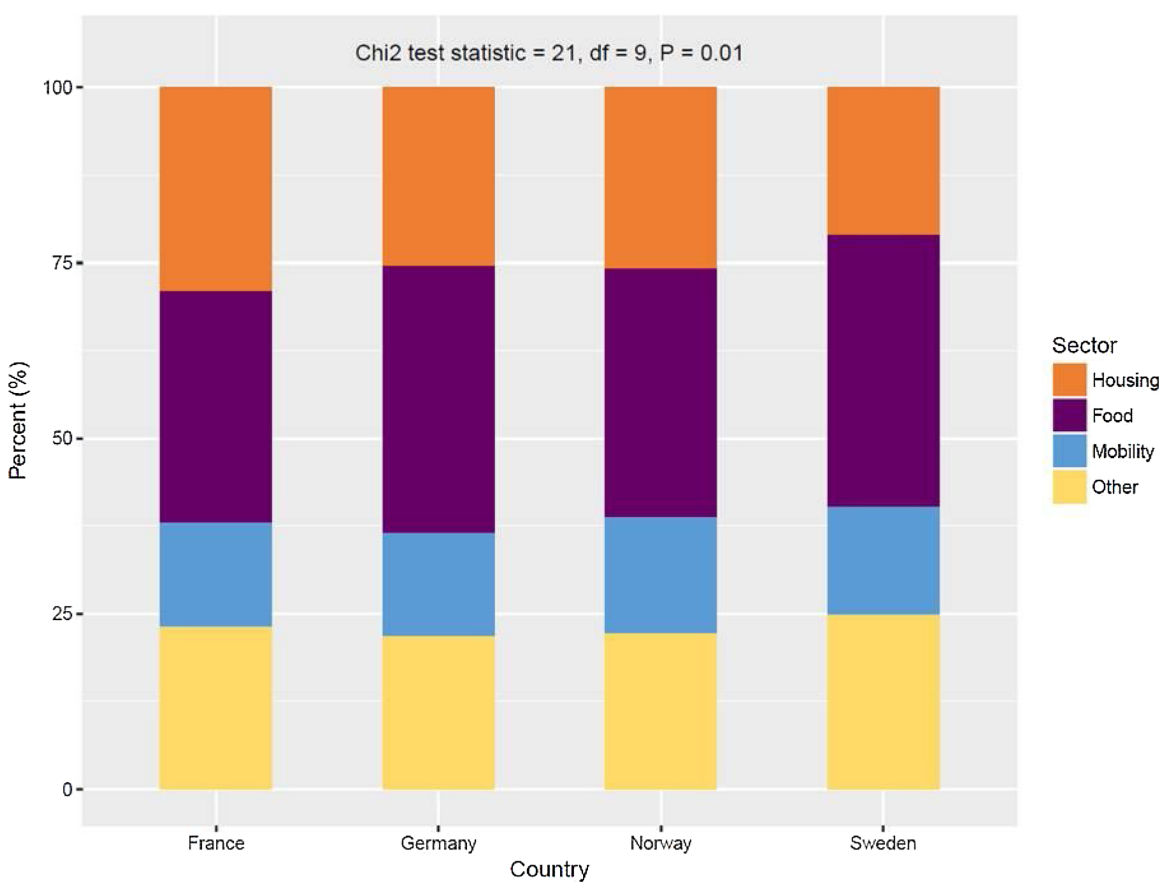

Fig. 2. Differences in voluntary carbon footprint reduction preferences by geographic location (country) for HOPE households.
Source: Authors.

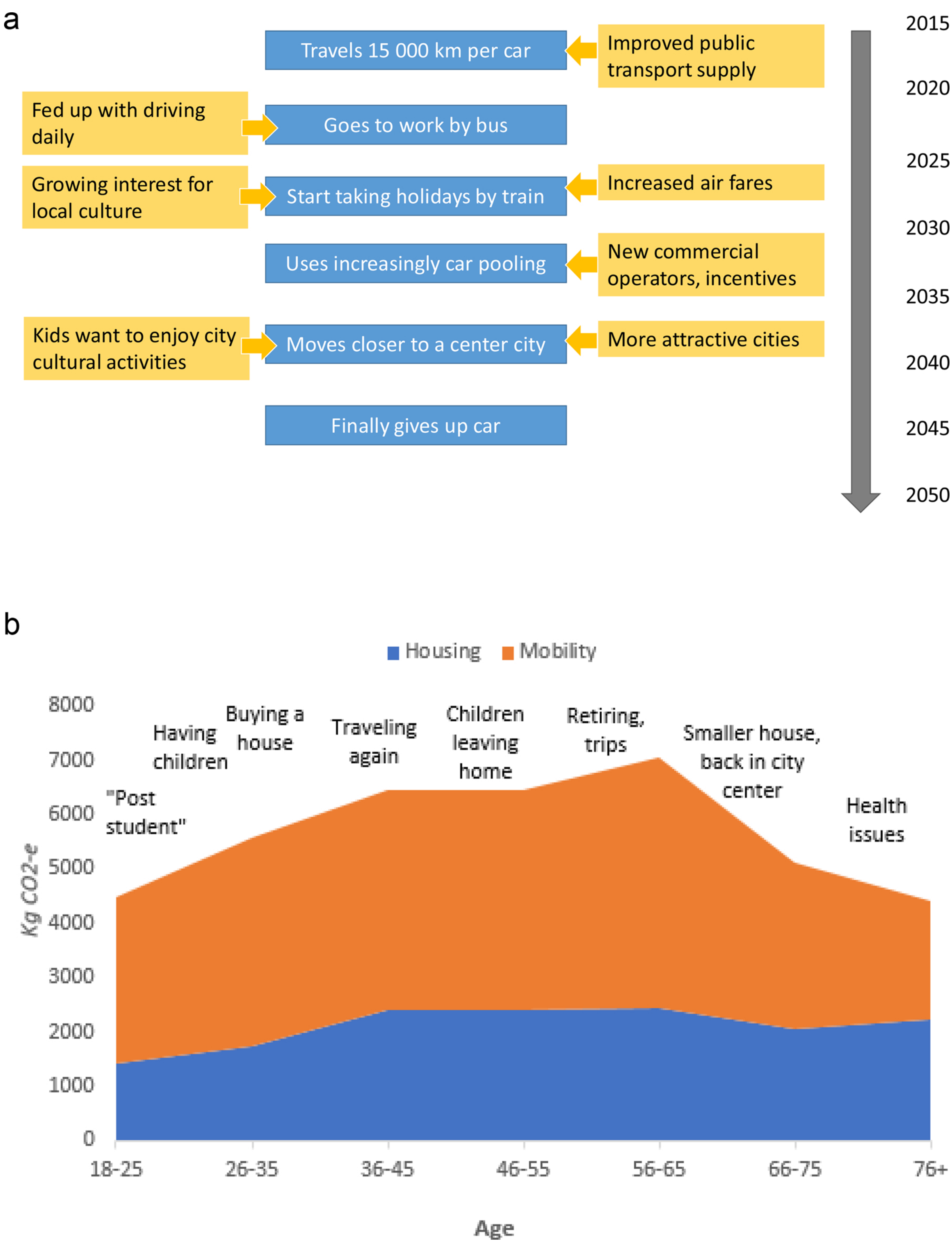

Fig. 3. The sequential and temporal nature of household carbon footprints. (a) Top panel: typical decision branching points for mobility related emissions. (b) Bottom panel: household lifestyles and changes in household and mobility carbon footprints based on major life events. Carbon footprints per consumption unit based on HOPE sub sample (n = 308).

"forced" one (20%). This is similar to the composition of total reductions (49%) in the housing sector (29% voluntary, 20% forced).

The relationship was turned around for mobility. In the mobility sector, they reduced more than half of their total reduction (59%) in the forced scenario (26% in the voluntary and 33% in the forced scenario). Voluntarily, households chose actions characterized by fairly incremental efficiency improvements such as eco-driving or substituting local public transport with walking and biking instead of more substantial changes such as reducing intercontinental flights or giving up their cars. More specifically, eco-driving (driving more efficiently) was the most popular mobility measure, and while buying a more eco-friendly car was chosen by 34% of households, only 4% were ready to give up their private car in the voluntary round. In particular, households that had flown were rather unwilling to replace even shorter transportation modes.

Basically, mobility is a more vexing issue to decarbonize because people attach personal values to it like having good relations with friends and relatives, experiencing cultural and natural diversity or getting a better education. As one household in Germany (male, 44 years old) explained when interviewed:

> *It is important to have a semester abroad in your CV. The companies think: Hey, this guy is motivated, he wants to learn, he is flexible, he has been to the US for a year. It sounds better, than saying: Oh well, yes, this guy is organic, he is climate-friendly, he decided to stay at home and not pollute the air.*

Their statement implies that international travel is key to status as well as individual perceptions of career ambition, education, and identity.

For food, the most popular actions were to buy goods with less packaging, eat less frozen/canned food, and eat 30% more local, 30% more organic and 30% more vegetarian food. Based on our household interviews, we know an important reason why participants were willing to reduce more in the consumption area of food was that climate-friendly actions were frequently connected to more positive values like animal welfare (e.g. better living conditions) and environmental protection (e.g. less use of fertilizer). As another household (female, 47 years old) in France mentioned during an interview:

> *If I buy milk or cheese, I want that the animals were kept properly and what is also important for me, is that the people, who are part of the production, earn proper money. And therefore I find it ok, […] if such food has its price.*

Put another way: the mitigation actions with highest willingness for implementation were moderate actions related to food and recycling [62].

However, to achieve the study target of a 50% reduction in footprints, households needed "forced" solutions because voluntary measures were insufficient. Somewhat perversely, the greater the CO_2e reduction potential of mitigation actions, the less household were willing to implement them [63], because the actions with greater mitigation potential reflect greater lifestyle changes. When looking at household choices of action cards to reduce their greenhouse gas emission, a negative association was found between voluntarily chosen action and reduction potential, as Fig. 4 illustrates. In this figure, the dots represent the 65 mitigation actions classified in the four consumption categories: other consumption, food, housing and mobility. The Y-axis shows the most chosen actions in the voluntary round. For each household sector, a negative association was present for mobility, food, and housing, but less for other consumption as the reduction potentials for this last sector are relatively low. For instance, 38% of participants voluntarily chose to eat 30% more vegetarian food, yet only 4% chose to become a vegetarian. Similarly, buying a more eco-

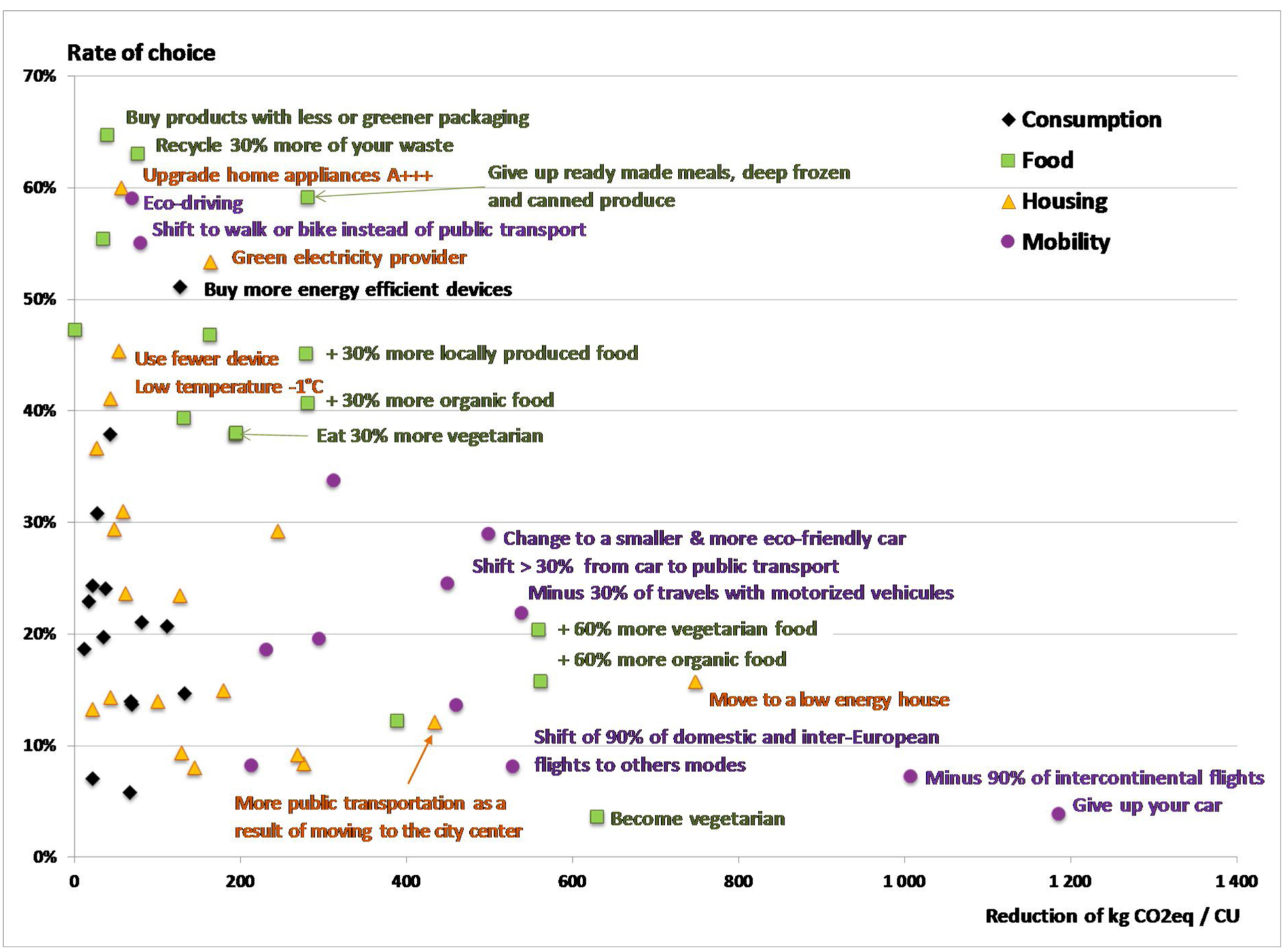

Fig. 4. Household preferences for mitigation actions and carbon reduction potential in the HOPE project.
Note: Each symbol represents one mitigation action. The *x*-axis shows how much reduction of CO_2e an action yielded for households (per consumption unit) on average. The *y*-axis shows the percentage of households that chose an action in the voluntary scenario. The colors correspond to the four different categories of consumption (food, mobility, housing, and other consumption). The reference of 100% are those households that were able to choose the specific actions. For instance, 128 out of all 308 households had used intercontinental flights at baseline. 10 of those 128 chose the action *reduce your intercontinental flights by 90%*. Thus, the action was unpopular and is found on the lower part of the panel. At the same time, the action is placed on the right side of the panel, as it yielded a large of CO_2e reduction per capita of about 1000 kg.

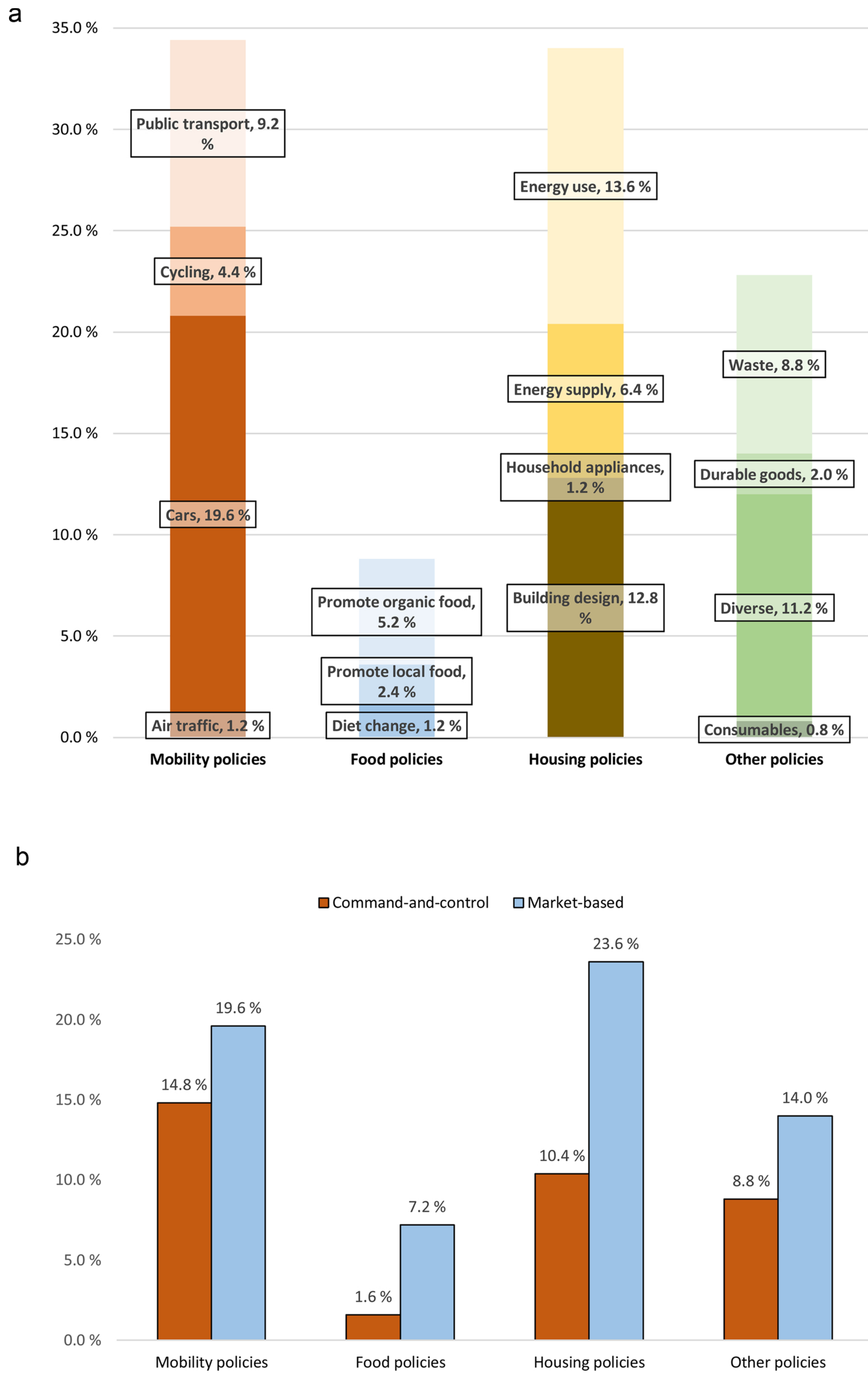

Fig. 5. Climate policies for household decarbonisation (n = 250). Top panel: share of identified climate policies in four high income countries (Sweden, Norway, Germany and France) aimed at altering private consumption. Bottom panel: share of policy-measures categorized as market versus command-and-control distributed among the four consumption areas in the HOPE project.

friendly car was chosen by 34% of households, yet only 4% were ready to give up their private car. This association vanished in the forced round, which shows that households then had to choose actions with high reduction potential to reach a reduction of 50%. The most greenhouse gas-reducing behavioral options were mainly chosen in the "forced" scenario.

3.5. Household perceptions do not always align with policy design

The HOPE analysis resulted in identifying a total of 250 distinct climate policy measures with the potential to influence household emissions, which we divided roughly into market based (economic instruments, information policies) and command and control (regulatory approaches and public goods and services). Our first finding was a mismatch between emissions and policy profiles, at least for the food sector, as it accounted for 30% of household greenhouse gas emissions but only related to 9% of policy measures on an unweighted basis, as Fig. 5 reveals.

For the other three sectors the share of emissions and policy measures more or less matched. More importantly, we found that the high-emitting consumption categories received the least policy attention, in particular aviation and diet changes. Only 1.2% of the policies identified correspond to each of the two, whereas emissions from aviation accounts for approximately 25% of total household emissions.[1]

Furthermore, categorizing the identified policy measures in our two main categories – market based versus command-and-control – reveals that different consumption areas were governed by different policy strategies. As the bottom panel of Fig. 4 indicates, the mobility sector had a rather high share of command-and-control policies. Governance in the three other sectors relies much more on market-based approaches. This dominance of market-based policy approaches individualizes responsibility for mitigation [25]. Consumers ultimately have to decide whether to mitigate or not, based on the prices they face, as well as their values, culture, habits, and the information they received. On the one hand, the policies influencing individual decisions in the two important areas of greenhouse gas emissions, air travel and diet, were almost exclusively market-based. Additionally, they received minimal policy attention. On the other hand, command-and-control policies were frequently used to lower emissions for housing and personal cars.

In our household interviews, we found that people often accept individual responsibility for their footprints, but at the same time called for government action to create consumption changes in areas with large, untapped mitigation potential. As one interview respondent from Sweden (female, 67 years old) put it:

> *I have already done a lot. What do others do, […] why should I care, when others don't? I can do the sacrifice […] and put climate first only if everyone helps. If it will be a law everyone has to do it.*

Thus, people such as this were only ready to act if everyone—including individuals and other societal players, like businesses and governments—acted in concert collectively. Households did not limit this collective action to the national sphere, but many emphasized that climate change mitigation could only work on the European or even international scale. In some areas, for instance changing to a more climate friendly diet by reducing consumption of meat, households called for stronger policy interventions that would make it easier for them to choose climate-friendly options. In less preferred mitigation areas, such as flying, stronger policy interventions (e.g. higher taxes or reduced availability of air travel) were only perceived to be acceptable if they would apply to "everyone". Many households understood that in less preferred areas with large untapped mitigation potential, such as mobility, only government-led infrastructural investments or other regulative acts could create substantial consumption changes, whether people liked it or not.

4. Conclusions

Households will undoubtedly shape future emissions pathways in complex and meaningful ways. They are influential stakeholders in climate polities with substantial control over emissions profiles in their respective households and countries. Yet their potential for achieving such drastic reductions in carbon footprints is uncertain. Rather than focusing mainly on household appliances, heat or electricity provision, our results suggest research and policy should deal with cars, air traffic, and eating meat. Mobility and food together accounted for about 64% of a HOPE household's initial median carbon footprint—emphasizing the salience of policies aimed in these directions to help mitigate climate change. Also, there is a gap between how households perceive their responsibility and ability to mitigate climate change and the responsibilities and roles communicated by climate policies. Addressing this mismatch requires that policy measures are selected that would materialize consumption changes in two high emitting areas of consumption: air travel and meat consumption. So far, scant attention has been paid to policy measures affecting these two areas, especially those that use command and control rather than the market. Perhaps this is because mobility and food are more difficult for households to conceptualize as major contributors to their footprints; or, that efforts to address mobility and food are seen as more personal, and tied to things like status and identity, and thus more likely to be unpopular.

We showed that demographic attributes such as household size and ownership status were more significant than geographic location in determining preferences for reducing carbon footprints. Household footprints were shown to shift significantly over time following a household lifecycle, as a function of major decisions (such as purchasing a car or home) or major life events (such as having children or getting divorced). This underscores both the necessity of targeting those specific events via policy as well as the important role that intermediaries related to those moments—estate agents for homes, retirement planners, and car dealerships [65]—can play in shaping preferences.

Importantly, households will only reduce about half of what they should to reach the reduction targets commensurate with reaching the 1.5 °C goal. Further substantial emissions reductions need strong and effective public policies incentivizing and supporting changes, the proverbial mix of carrots and sticks. Even then, mobility seems to be "stickier" [66] and more difficult to decarbonize. We need to rely on stronger policy interventions more than, or at least in addition to, altruism. This may require limiting availability of GHG-intensive consumption through regulative instruments like bans and restrictions or coercive economic instruments such as a "considerably higher" carbon tax on fuel [67]. This should be balanced with making less GHG-intensive alternatives more readily available, both financially and structurally [68]. The good news is such actions do have support, a social license or broader legitimacy, among HOPE participants.

Driving changes in attitudes, norms, or practices could shape consumption habits - and thus create motives for further voluntary changes to then emerge [69]. Nonetheless, we may have to rely on forced consumption changes in order to buy us time to take advantage of technology. Fortunately, the HOPE project documents a high willingness to accept some moderate lifestyle changes, for instance related to food. Therefore, we believe that regulations targeting areas such as less packed food or more local and organic farming will be supported and even be cherished by the public. However, areas such as mobility (especially air travel) are more difficult. An intelligent mix of improving infrastructure and creating incentives as well as regulating in specific

[1] This share of emissions from aviation is higher than an average country, given all four countries have higher per capita carbon footprints to begin with, have higher than average incomes, and likely have more "high fliers" or "frequent flyers," especially the Scandinavian countries.

areas is needed to ensure change in mobility behavior. Positively, the HOPE project affirms a potential to accept radical changes in consumption among households of high-income countries as longs as this is done in a fair way.

Essentially, household decision-making and behavioral change are neither the silver bullet of climate policies, nor purely a consequence of climate (or energy) policies. Households demand goods and services that propel economic development and consequently drive emissions patterns, yet they also reflect broader patterns of infrastructures, technologies, organizations, markets and practices. Households therefore embody the potential to become either active agents of decarbonisation, or aggressive culprits accelerating dangerous emissions.

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Appendix A

As previously mentioned, the HOPE project relied on a mixed methods protocol involving: (1) the estimation and mapping of household carbon footprints, (2) the output of a climate change mitigation simulation game with households, (3) in-depth qualitative interviews, and (4) the depiction of climate policy measures that are explicitly or implicitly aimed at influencing household consumption in order to reduce greenhouse gas emissions. All greenhouse gases were considered and accounted for as CO_2e. More details on the methods can be found in the published study protocol [70].

Sampling and Recruitment

We recruited participants by sending letters with support of the local municipality to a random sample of inhabitants of each city. If the needed sample size could not be achieved in the respective case study city by this method only, we filled up the sample by recruitment via media engagement. To encourage participation and minimize the risk of selection bias (i.e., that only environmentally concerned people would participate), we offered a secure financial and a lottery incentive, thus appealing to risk-averse and risk-seeking individuals. Such incentives are common, and have been "used extensively for many years" in the research community to improve response and participation rates [71], although it could also mean more opportunistic respondents took part. The sample composition is given in Fig. A1.

Method 1: Mapping empirical household carbon footprints

The FCS-Tool first calculated the carbon footprint of each participating household after detailed data about each households' consumption habits in the four sectors of Food, Mobility, Housing and Other Consumption were entered. The tool considered formulas to calculate the carbon footprint by combining the questionnaire inputs on consumption habits (e.g. the kilometers of car use per year and information about the type of car used) and the corresponding emission factors (e.g. CO_2e emissions per kilometer for this specific type of car). The emission factors were either taken from a common database (the IMPACTS database of the French Environment and Energy Management Agency) or from other databases adapted to the national contexts whenever necessary (e.g. emission factors for electricity depending on the national or regional energy mix). The individual household inputs on consumption resulted from a detailed online questionnaire, which covered many items of personal consumption with the exception of public services. The online questionnaire also asked for spending in all consumption areas and socioeconomic characteristics of the household. Households usually spent 1.5–2 h to fill in the questionnaire. In a second step the FCS-Tool prepared mitigation actions for each household. Each of these actions went along with individually tailored estimations on the potential CO2e-savings, financial costs and savings as well as generic information on health co-benefits for each specific household. These mitigation actions were the basis for the simulation game, described under Method 2.

Method 2: Conducting a mitigation simulation game with households

At the beginning of our simulation game, which was conducted as a personal on-site interview with each household, we confronted the household with their current carbon footprint, calculated with data from the online questionnaire. Then we offered households an array of up to 65 climate change mitigation actions, which they could implement. Those mitigation actions were presented on "Action Cards" and included information about avoided CO2e emissions, positive or negative financial costs, and health impact if applicable (for examples of actions cards see Fig. A2). The number of actions varied for each household, as some actions were rated as "already done" (e.g. already vegetarian) or "not applicable" (e.g. not able to insulate a roof because of living as tenant on the ground floor).

In order to create a realistic atmosphere and engage households into the complex social problem of climate change, we adopted a serious gaming approach. This means that we invited households to imagine a scenario, in which they were required to reduce their carbon footprint by 50% by 2030. Staying in this frame we first made households familiar with all mitigation actions by asking them to rate all actions on a Likert Scale from 1-5. We then asked households to choose voluntary actions: "Which actions would you actually like to implement to reduce your carbon footprint by 50% by 2030?" We then entered the chosen options into the FCS-Tool and confronted households with the resulting CO2e-reduction for their household. If it was less than 50%, we asked them to choose more or other options to reach the set goal: "Which actions would you choose if you were forced to reduce your carbon footprint by 50% by 2030? Continue your rank order for round 2. You may choose up to 30 actions in total." Having a "voluntary" and a "forced" scenario allowed us to distinguish the spontaneous choices from the ones that were made, because they were necessary to reach the set goal. At the end of the simulation game, households were presented with a visual presentation of their achieved reduction in general and in each of the four sectors of Food, Mobility, Housing and Other Consumption.

Within the simulation process the tool detected dynamically incompatible options (e.g. one cannot reduce car use when one had previously decided to give up the car) and re-computed the resulting carbon footprint dynamically (e.g. if one first chooses to insulate and then change the

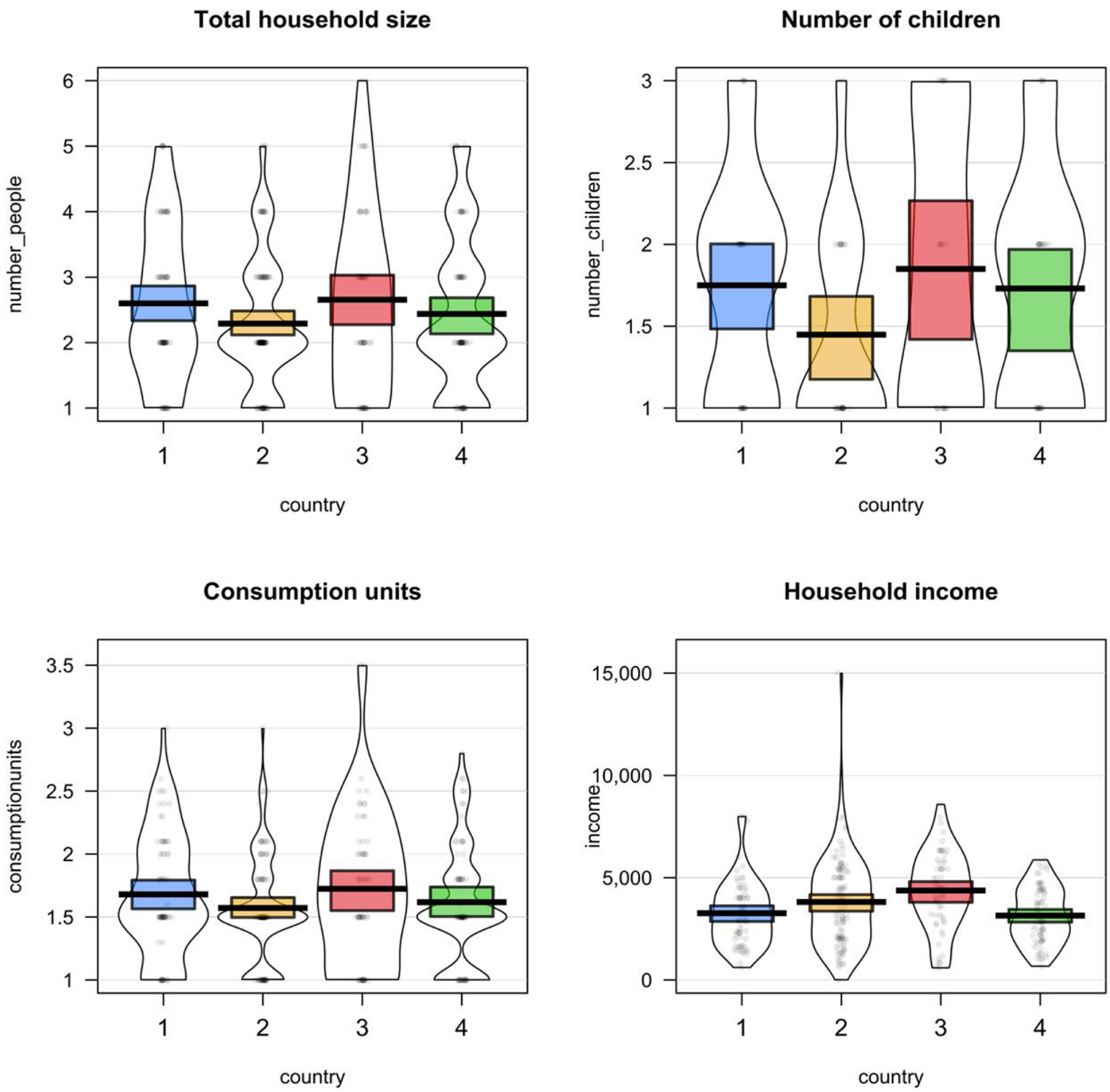

Fig. A1. Sample composition for the HOPE Project giving total household size, number of children, and consumption units (household income in Euros weighted by household size and composition, and household income per household). Please note: Country code denotes 1 = France, 2 = Germany, 3 = Norway, 4 = Sweden.

heating system, the CO_2e reduction of changing the heating system is lower than if considered alone). Thus, our simulation offered realistic options for each household and avoided double counting. Furthermore, it visibly displayed the results to households, which made the simulation more realistic.

For the results in part 3.2 a Multiple Component Analysis (MCA), was performed for *the simulation 2 – Round 1* (Rating on Likert scale of mitigation options). This analysis captures the correlations between socio-demographic household characteristics, home attributes, expenditures and energy consumptions (illustrative variables) and their preferences for reducing their carbon footprint (active variables, options rated from 1 to 5).

When conducting our MCA, we relied on the techniques suggested by Lebart et al. [72] with notations adapted from Greenacre [73]. Consider a survey conducted on N respondents who are being asked to answer Q questions each with say m_q modalities. Clearly, in our case we have $N = 309$ HOPE respondents and $Q = 65$ actions to be ranked, each with $m_q = 7$ modalities.

Thus the modalities encompass the 5 likert ranking scores plus missing and not feasible modalities. We call **S** the $N \times Q$ matrix of responses over the 65 HOPE actions holding the modality value s_{iq} of respondent i to question q: an interger between 1 and 7. Let us call $M = \Sigma_{q=1}^{Q} m_q$ the total number of modalities over the Q questions. In our case, $M = 65 \times 7 = 455$ modalities. Now, matrix **S** is not suitable for computations which are actually performed with the $N \times M$ matrix **Z** of indicator variables corresponding to **S**. Matrix **Z** holds the modality indicator variable for each of the q questions with for each question q, $z_{ij} = 1$ if modality j was chosen and 0 otherwise. Clearly, because each question has only one nonzero modality, the row sums are constant and equal to the total number of questions, Q. Meanwhile, column sums give the marginal frequencies of each category.

The computational derivation that is more common in the "French Way" makes use of duality between row and columns. Under the same notations seen above, from $\mathbf{P} = (1/NQ)\mathbf{Z}$, define, $\mathbf{D}_M = \frac{1}{NQ}\mathbf{D}$ where **D** is the diagonal matrix holding the diagonal elements of $\mathbf{B} = \mathbf{Z}^{\mathbf{T}}\mathbf{Z}$, (an interesting matrix in itself because it represents the cross-tabulation of all the modalities two by two, the diagonal holding the frequency of the modality over the whole sample), and $\mathbf{D_N} = \frac{1}{N}\mathbf{I_N}$, with $\mathbf{I_N}$, the identity matrix of order N. The factorial axes $\mathbf{u}_\alpha$ are found by diagonalization of the matrix: $\mathbf{T} = \mathbf{F}^{\mathrm{T}}\mathbf{D}_{\mathbf{N}}^{-1}\mathbf{F}\mathbf{D}_{\mathrm{M}}^{-1} = \frac{1}{Q}\mathbf{Z}^{\mathrm{T}}\mathbf{Z}\mathbf{D}^{-1}$. It follows that in $\mathbb{R}^{\mathrm{M}}$, the equation of the α^{th} factorial axis is $\mathbf{u}_\alpha$ is: $\frac{1}{Q}\mathbf{Z}^{\mathrm{T}}\mathbf{Z}\mathbf{D}^{-1}\mathbf{u}_\alpha = \lambda_\alpha \mathbf{u}_\alpha$, meaning that axis $\mathbf{u}_\alpha$ is eigenvector of $\frac{1}{Q}\mathbf{Z}^{\mathrm{T}}\mathbf{Z}\mathbf{D}^{-1}$ associated to eigenvalue λ_α. Then, we define the equation of the α^{th} factor as $\boldsymbol{\varphi}_\alpha = \mathrm{D}^{-1}\mathbf{u}_\alpha$, that is written: $\frac{1}{Q}\mathbf{D}^{-1}\mathbf{Z}^{\mathrm{T}}\mathbf{Z}\boldsymbol{\varphi}_\alpha = \lambda_\alpha \boldsymbol{\varphi}_\alpha$.

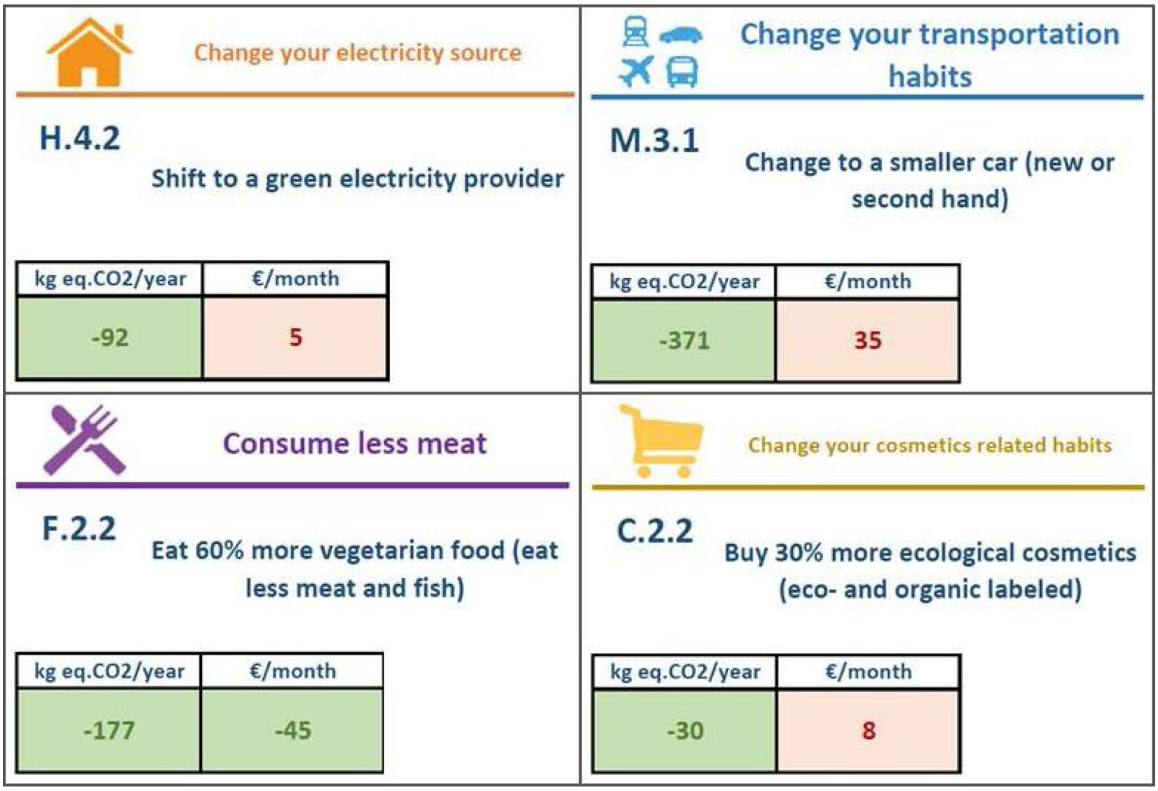

Fig. A2. Examples for action cards in the four areas of mitigation (Housing, Mobility, Food and Other Consumption) for the HOPE Project, including individually tailored information on expected CO_2e savings per year and financial costs or savings per months.

Likewise, the equation of the α^{th} factor ψ_α in $\mathbb{R}^N$ is written: $\frac{1}{Q}\mathbf{Z}\mathbf{D}^{-1}\mathbf{Z}^T\psi_\alpha = \lambda_\alpha\psi_\alpha$. Thus, we can see the duality relationship between row and columns in MCA, as the factors $\boldsymbol{\varphi}_\alpha$ and $\boldsymbol{\psi}_\alpha$ represent respectively the coordinates of lines and columns on factorial axis α. Notice that both factors have the same norm: λ_α, the eigenvalue associated to each factorial axis. Transition relations between factors $\boldsymbol{\varphi}_\alpha$ and $\boldsymbol{\psi}_\alpha$ are thus: $\varphi_\alpha = \frac{1}{\sqrt{\lambda_\alpha}}\mathbf{D}^{-1}\mathbf{Z}^T\psi_\alpha$ and $\psi_\alpha = \frac{1}{Q\sqrt{\lambda_\alpha}}\mathbf{Z}\varphi_\alpha$.

Practically, computations are performed in the smallest space since the transition formulae allow to deduce coordinates in the dual space once given. Generally, since observations are far more numerous than variables, one prefers to perform the computations in the column space and thus, compute eigenvalues in column space, or $\boldsymbol{\varphi}_\alpha$ factors. The reverse is true in our case, since we know that $N = 309$ but $Q = 455$, thus we performed the computation in row space, and the factors are the $\boldsymbol{\psi}_\alpha$. As a last remark, we can conduct the MCA with two distinct data tables: either the complete disjunctive table $\mathbf{Z}$ or the cross-tabulations hypercube $\mathbf{B}=\mathbf{Z}^T\mathbf{Z}$. It can be shown that the factors are the same, and thus the results at the exception of the eigenvalues that are the square roots of those in the $\mathbf{B}=\mathbf{Z}^T\mathbf{Z}$ case.

The case of illustrative variables does not pose any difficulty. We must find a way correlate the illustrative variables with the results of the MCA. For categorical variables, this does not pose any problem: one just adds news questions and modalities and finds directly their coordinates through the transition formula for $\boldsymbol{\varphi}_\alpha$ because the factorial coordinate of any modality on any axis is just the product of the inverse square root of the axis eigenvalue by the arithmetic mean of $\boldsymbol{\psi}_\alpha$ coordinates of the individuals who have the given modality. Thus, any illustrative categorical variable may be projected on a given MCA, provided they are observed on the same individuals.

The descriptive preferences analysis in part 3.4 is based on the results of simulation two, rounds two and three, voluntary and forced scenarios. The percentage of households that chose an action is related to the total households for which the action is applicable, and not already done (see above). The CO_2e reduction potential is an average of the household sample, it refers to the initial potential of CO_2e reduction, computed by the Footprint Calculation and Simulation Tool for each household, and presented on the action cards.

Method 3: Qualitative household interviews

We conducted semi-structured interviews with 64 households, transcribed all interviews verbatim and analyzed them using qualitative content analysis. Table A1 summarizes the main questions from the interview guide.

Method 4: Policy analysis

Here we provide some more details about the categories we used to code the 250 policies, which we analyzed in our policy analysis. Even more details can be found in the article by Moberg et al. [25].

The policies were first sorted in four main consumption areas, similar to those used in the simulation game: Housing, Mobility, Food and Other Consumption.

Secondly, we sorted the policies in accordance to the anticipated policy mechanisms; i.e. how the policies affect household consumption and as a result of that, GHG emissions. This could happen either though changes in patterns or volume of consumption, and changes in patterns can happen

Table A1
Main questions and illustrative scenarios of the interview guide for the HOPE Project.

1. Introduction:
Explanation of how the interview works, what are the objectives, presentation of the interviewer etc.

2. Warming up
- How come you signed up for the study?
- *Info for the interviewer: Go through the HHs carbon footprint from the simulation initial footprint and final footprint with the informant. Ask:* What do you think about this today?
- What is your thinking regarding climate change more in general?
- Do you have a personal interest in climate change issues/any personal experience?

3. Climate change mitigation
a) Household changes
- *Show the HHs first 2-3 options from I2 one by one, step 2 first and step 3 thereafter and some actions they did not chose (to capture attitudes to voluntarily versus forced changes). Ask:* How come you made these choices? (step 2 first, step 3 thereafter and non-choices last)
- Seeing yourself in a low carbon future – what do you think it would mean for people in general (probe on quality of life/lifestyle/health, economy)?
- In the HH follow up questions you ranked the importance of some aspects when it comes to implementing your selected actions (1= most important, 3= least important). You ranked XX highest and XX lowest. What do you think about the answers today? What is the most important for you today?

b) Health co-benefits of CC mitigation (not relevant for this paper)
c) General changes
- *Info for the interviewer: Look at the HH's responses in HH follow up question 7 from the simulation* (Q7 « 1) Climate change is a serious and pressing problem. We should begin taking steps now even if this involves significant costs. 2) The problems of climate change should be addressed, but it effects will be gradual, so we can deal with the problem gradually by taking steps that are low in cost. 3) Until we are sure that climate change is really a problem, we should not take any steps that would have significant costs ») *Ask:* In the follow up questions after the climate game you wrote that the statement XX comes closest to your view. Please explain how you reason?
- What are your feelings regarding climate change? (Anxiety, guilt, anger/frustration ...). How come?
- How do you see the future in a world where the climate changes?
- How do you believe climate change will affect population health, as well as your health?
- Who do you consider responsible for climate mitigation? (Probe on the role of government, industries, community, HH)
- How do you judge the possibility that we in (own Country) will succeed as a country to reach the EU targets? (Inform about the targets set before asking)

4) Motivation and barriers for change
a) Perceptions on implementing -50% changes
- *Read out and ask:* In December 2015 there was an UN agreement to limit global warming to 2 degrees Celsius, and pursue efforts to limit warming to 1.5. This means that large scale emission reductions are needed. That is why we in the climate game asked you to reduce emissions by 50% by 2030. How do you feel about halving your HHs carbon footprint, does it mean big sacrifices or is it easy? What would the consequences be for you?
- What would have to happen regarding effects from climate change to make you implement bigger changes, major ones compared to today? (Ex. For probing: close or distant changes, weather extremes/variability, disasters, access to clean water/air, heat waves, infectious disease transmission etc.)
- *Show the HHs first ranked 2-3 options from I2 step 3, one by one, and thereafter the lowest 2-3 prioritized options. Ask:* Based on the climate game - you prioritized this action high, how come? What would you need to be able to accomplish this? You gave this a low priority. How come?
- What information/what kind of support would you need to implement major changes?
- *Info for the interviewer: Show the HH follow up question number 6* "To what degree are you intending to implement in the near future the actions you have selected in the third round of the interview? (Please show their ranking: 1= "not at all" to 5 = "likely"). *Ask:* How do you today view the realism in implementing your forced choices?
- Why did you choose xx and not xx when it came to forced choices (for example, what made you choose to become vegetarian in order to reduce your CF and finally hit 50% reduction and not to reduce your flights)?

b) Household change scenario

Info for the interviewer: There are several different scenarios below. Prepare before the interview so there is an idea on what scenarios to use. Choose ONE that you judge relevant for the HH you interview. If it is a HH with many children number 4 may be extra interesting or if it is a technology interested HH number 5 might be most interesting.

One example for the scenarios out of five given scenarios: Imagine that you have children who want to travel abroad on holidays and who you also want to show some nice places. But you know that travelling is not climate-friendly, and you want our planet to remain healthy for the next generation. How do you feel about this? How would you do yourself? What would make it easier for you to act in accordance with your own values?

c) Household specific question (only if there was something interesting noted from I2)
d) Country specific policy scenarios:

Info for the interviewer: Use TWO scenarios fitting (the HH and) your own country/city illustrating the conflict between government regulation and freedom to choose individual action.
One example for the proposed scenarios (2 scenarios per sector were available): Imagine the (country) government would prohibit the sale of (new) cars with a conventional engine (diesel or gasoline) from 2030. This could be similar to bans on oil furnaces for heating of buildings that are already introduced in some cities (ex. Bergen). What do you think about this? How do you feel about such decisions made by others? (OBS! This is suggested to be introduced on new cars in Norway by 2025, although not concluded).

Table A2
Policy instruments considered as marked based or command-and-control in the HOPE policy analysis.

Market-based approaches:	Command-and-control approaches
• Audit processes • Enforced self-regulation • Regulated participation bodies • Competition focus • Marketization and privatization of public services • Personal responsibility to act • Self-surveillance measures • Standardization, benchmarking, best practice schemes, performance indicators	• Legislative and regulative measures • Responsibility to act within bureaucratic apparatuses • Public services provided by the state

either by improving efficiency (e.g. change into a car with better mileage) or substituting consumption (e.g. substitute private car use by public transportation). An example of reducing consumption is to simply travel less [74].

Finally, we applied the same formal categorization of policy instruments as in the latest IPCC main report, in which we differed between main categories of instruments: economic instruments (credits, grants, taxes, tax deductions), information policies (information campaigns, research requests, suasion), and public goods and services (planning, public company, infrastructure). The IPCC categories can also be divided into marked-based approaches or command-and-control approaches, as we have done in Fig. 5 of this paper, above. Table A2 contrasts these approaches [75–79].

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